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Disk and Washer Cavity Tuning

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The "frequency test" phase of the Disk and Washer (DAW) linac program for Fermilab is nearing completion. After seven iterations on the geometry, the final dimensions are derived below, that will result in an accelerating mode and a coupling mode that will resonate at 805 MHz, under vacuum conditions. This derivation involves:

1) an analysis of the effect of the laboratory atmosphere on the measured frequencies,

2) four measured frequencies (f_{3c}, f_{1c}, $f1_{cp}$, and f_{2a}) and three variable dimensions R (disk inner radius), and N (nose extension) and T (half disk thickness) for the seventh and semi-final geometry,

3) two SUPERFISH frequencies (f_a and f_c) for the seventh geometry, and

4) partial derivatives for the two mode frequencies with respect to the three variable dimensions ($\Delta f_a/\Delta R$, $\Delta f_a/\Delta N$, $\Delta f_a/\Delta T$, $\Delta f_c/\Delta R$, $\Delta f_c/\Delta N$, and $\Delta f_c/\Delta T$).

Certain redundancies exist in these data and serve as a check on their validity. For example, the four measured frequency offer one direct, and one indirect, measure of the resonant frequency of the coupling mode in the T-Bar perturbed cell. Their comparison justifies the linear combination of frequencies used in this analysis. The single-cell coupling mode frequency, after correction for atmospheric effects, should be compared to the calculated coupling mode frequency. The difference between the "measured" infinite chain coupling mode frequency, after correction for atmospheric effects, and the calculated coupling mode frequency is a measure of the T-Bar perturbation to the coupling mode. The difference between the measured accelerating mode frequency, after correction for atmospheric effects, and the calculated accelerating mode frequency is a measure of the T-Bar perturbation to the accelerating mode. During the course of the frequency test exercise, there were numerous oppurtunities to use and verify the calculated partial derivatives.

The laboratory atmosphere, in the cavities during the frequency tests, lowers their resonant frequency by $1/\sqrt{\mu\varepsilon}$ or $1/n$, where μ is the relative permeability of the atmosphere, ε is the dielectric constant of the atmosphere, and n is the index of refraction of the atmosphere. The index of refraction for dry air (760 mm-Hg, 0 C) is 1.000288. The atmospheric pressure decreases by

3.3% per thousand feet of altitude. The valve of (n-1) for water vapor is 0.000060 per 10 mm-Hg of partial pressure. The vapor pressure of water at 20 C is 17.535 mm-Hg. Taking the altitude of the laboratory (Fermilab) to be 600 ft. and the humidity in the laboratory to be 20%, the effective index of refraction is

$$n = 1 + 0.000288*(1-0.6*0.033) + 0.000060*0.2*1.7535 = 1.000303.$$

Hence, measured frequencies should be multiplied by 1.000303 to yield their valve in vacuum. Conversly, cavities aimed at 805 MHz under vacuum should be tuned to 804.756 MHz in the Laboratory.

The dimensional and frequency data for the seventh step of the tuning exercise are presented in Table I. The derivation of the final DAW dimensions are presented in Table II.

TABLE I DIMENSIONAL AND FREQUENCY DATA (Seventh Step)

Dimensions (cm)		
R (radius of disk)		19.857
N (nose extension)		2.890
T (half disk thickness)		1.336

Measured Frequencies (MHz)	measured	corrected
f_{3c} (3-cell, c-mode)	798.0418	798.2836
f_{1c} (1-cell, c-mode, unperturbed)	782.9361	783.1733
f_{1cpt} (1-cell, c-mode, perturbed)	826.7761	827.0266
f_{2a} (2-cell, a-mode)	796.8417	797.0831

Inferred Frequencies (MHz)	
$f_{c\infty}$ $(3*f_{3c} - f_{1c})/2$	805.8387
f_{1cpx} $(3*f_{3c} - 2*f_{1c})$	828.5042

SUPERFISH Frequencies (seventh-step geometry) (MHz)	
f_a (accelerating mode)	799.489
f_c (coupling mode)	786.825

Partial Derivatives (SUPERFISH) (MHz/cm)	
$\Delta f_a / \Delta R$	1.698
$\Delta f_a / \Delta N$	-63.720
$\Delta f_a / \Delta T$	-6.400
$\Delta f_c / \Delta R$	69.038
$\Delta f_c / \Delta N$	0.020
$\Delta f_c / \Delta T$	-5.200

TABLE II DERIVATION OF FINAL DAW DIMENSIONS

Frequency Goal (vacuum) 805.000 MHz

Thicken disk by 1 mil (0.0025 cm) for copper plating

f_{2a} = 797.0831 + .0025 * (-6.400) = 797.0671 MHz

$f_{c\omega}$ = 805.8387 + .0025 * (-5.200) = 805.8257 MHz

Interpolate for R

R = 19.857 + (805.000 - 805.8257)/69.038 = 19.845 cm

Evaluate f_{2a} for New R Value

f_{2a} = 797.0671 + (-.012) * 1.698 = 797.0467 MHz

Interpolate for N

N = 2.890 + (805.000 - 797.0467)/-63.720 = 2.765 cm

* * * * * * Machinist's Dimensions * * * * * *

Radius (R) in inches plus 1 mil for copper plating	=	7.814 inches
Disk Diameter (ID before plating)	=	15.628 inches
Disk Diameter (ID after plating)	=	15.626 inches
Nose Extension (N)	=	1.089 inches
Total Disk Thickness (2T) (before plating)	=	1.052 inches
Total Disk Thickness (2T) (after plating)	=	1.054 inches